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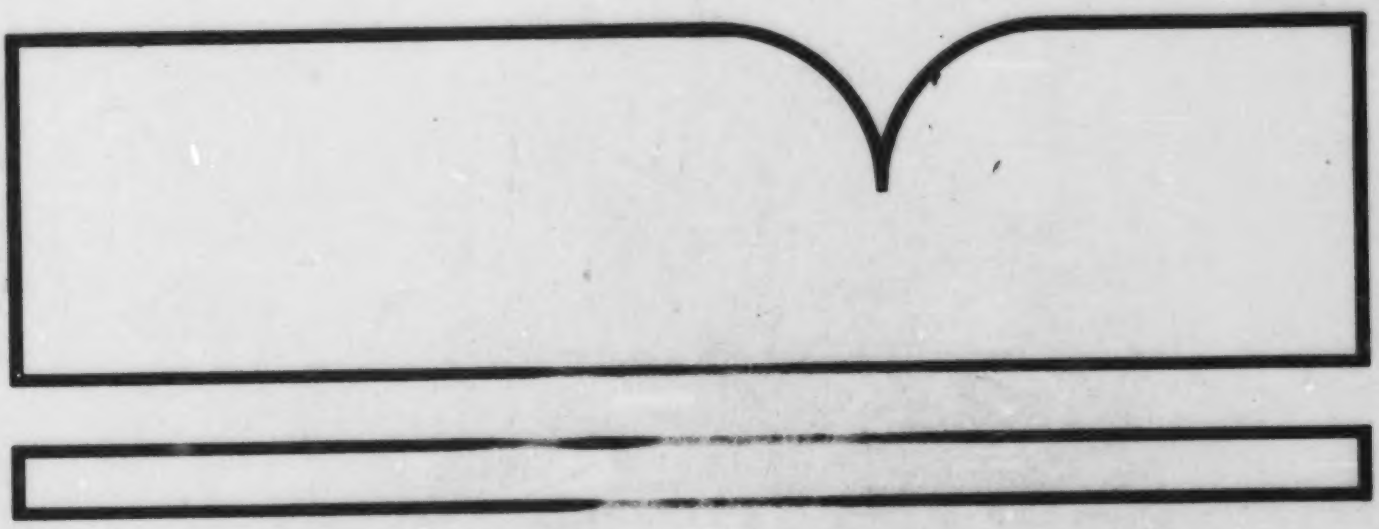
Engineering Assessment of Hot-Acid Treatment of Municipal Sludge for Heavy Metals Removal

Camp, Dresser and McKee, Inc.
Boston, MA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Jan 82



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ENGINEERING ASSESSMENT OF HOT-ACID TREATMENT OF MUNICIPAL SLUDGE FOR HEAVY METALS REMOVAL

by

Camp Dresser & McKee Inc.
Boston, Massachusetts 02108

Contract No. 68-03-2803

Project Officer

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16. ABSTRACT The hot-acid method for treating sludge was developed by the Walden Division of Abcor, Inc., to remove heavy metals from municipal wastewater sludge. Investigations by Walden have demonstrated the degrees to which heavy metals are solubilized. Sulfuric acid dosage at about 20 to 30 percent of the sludge dry solids followed by heating to 95 °C for a 30-minute reaction time are the process' design parameters.

The process is effective in solubilizing about 50 to 90 percent of the concentration of the selected heavy metals. The nitrogen, phosphorus, and organic contents of sludge are also solubilized to varying degrees. The acid-treated sludge was found to be essentially pathogen-free.

Dewatering of the treated sludge was shown to be poor. It was determined that untreated sludge requires about four times as much land as hot-acid treated sludge for land application, based on the EPA stipulated cadmium application rate. Hot-acid treatment would not reduce the sludge's metal levels below the USDA recommended guidelines for land application. However, hot-acid treatment clearly improved marketability of a high metals sludge.

The hot-acid treatment of sludge would cost about $440 per ton for a 2-mgd wastewater treatment plant and about $140 per ton for a 20-mgd plant. Although hot-acid treatment is costly when compared to conventional sludge treatment practices, its cost effectiveness may be quite good when compared to other systems aimed at controlling the heavy metal contents of sludge.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report entails an engineering and economic investigation of the so-called hot-acid treatment process for municipal wastewater sludge. As developed by the Walden Division of Abcor, Inc., Wilmington, Massachusetts, the process is primarily aimed at solubilizing heavy metals contained in the sludge by the addition of sulfuric acid. Components of the process include: acid addition and mixing, heating to just below boiling, heat recovery, dewatering, and neutralization of dewatering sidestream and sludge cake. The sludge cake product contains less metals and is more marketable for soil-conditioning purposes. The sidestream contains high metal concentrations which are precipitated by neutralization, dewatered, and disposed to secured landfills.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory, Cincinnati

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ABSTRACT

The hot-acid method for treating sludge was developed by the Walden Division of Abcor, Inc., Wilmington, Massachusetts to remove heavy metals from municipal wastewater sludge. Investigations by Walden have demonstrated the degrees to which several heavy metals are solubilized. Sulfuric acid dosage at about 20 to 30 percent of the sludge dry solids followed by heating to 95°C for a 30-minute reaction time are the process' design parameters.

The process is effective in solubilizing about 50 to 90 percent of the concentrations of selected heavy metals. The nitrogen, phosphorus, and organic contents of sludge are also solubilized to varying degrees.

Dewatering of the treated sludge was shown to be poor. However, the hot-acid treated sludge product was assessed assuming successful dewatering. For illustration, it was determined that untreated sludge from Milwaukee, WI requires about four times as much land as hot-acid treated sludge for land application, based on the EPA stipulated cadmium application rate. Using sludge data from New York City, it was determined that hot-acid treatment would not reduce the sludge's metal levels below the USDA recommended guidelines for land application. However, hot-acid treatment could enable a sludge with less metal content than New York City's to become a more marketable product.

The hot-acid treatment of thickened primary and waste activated sludge would cost about $440 per ton for a 2-mgd wastewater treatment plant and about $140 per ton for a 20-mgd plant. Dewatering costs are excluded from these costs because successful dewatering performance data is not available. Although hot-acid treatment is costly when compared to conventional sludge treatment practices, its cost-effectiveness may be quite good when compared to other systems aimed at controlling the heavy metal contents of sludge.

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The "Engineering Assessment of Hot-Acid Treatment of Municipal Sludge for Heavy Metals Removal" was prepared under the direction of Mr. Paul W. Prendiville, officer-in-charge, and Dr. Albert B. Pincince, project manager. The principal investigator was Mr. Patrick J. Connelly (project engineer). The assistance of Ms. Suzanne M. Belleville is gratefully acknowledged.

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SECTION 1

INTRODUCTION

Some wastewater sludges contain high concentrations of heavy metals that make them unsuitable for application to agricultural land. One way to improve the quality of these sludges would be to remove the metals from the sludges. To do this, the Walden Division of Abcor, Incorporated, Wilmington, Massachususetts developed the hot-acid process.

In the hot-acid treatment of sludge, acid and heat are applied to municipal wastewater sludge to decrease the sludge's pH to between 1.5 and 2.5 and increase its temperature to about 95°C. The aim of the process is threefold: to stabilize the sludge, to condition the sludge for dewatering, and to solubilize heavy metals. After dewatering, the bulk of the heavy metals would be in the sidestream. The cake solids would contain less heavy metals. Walden explained the process in a report entitled, "Evaluation of Hot Acid Treatment for Municipal Sludge Conditioning" (Walden Div. of Abcor, Inc., 1979). Their report documents and discusses the results of bench-scale tests conducted by Walden to evaluate the technical and economic feasibility of the process.

The EPA engaged Camp Dresser & McKee Inc. to review the report and perform an economic and engineering assessment of the process. The work was carried out as Work Effort No. 4 under contract No. 68-03-2803 issued by EPA's Municipal Environmental Research Laboratory, Office of Research and Development.

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SECTION 2

CONCLUSIONS

The major advantages of the hot-acid treatment process are the decreased land area requirements for land application and the increased marketability of the sludge product associated with low metal levels. We determined that for a municipal sludge with relatively high heavy metal levels, area required for application of hot-acid-treated sludge is one-quarter that for raw sludge. This is based on the greater application rate per acre possible for hot-acid sludge than for untreated sludge, based on its lower cadmium content. The smaller land area requirement is a strong-point in favor of hot-acid treatment when available land is constrained. However, cost savings are minimal when sufficient land is available.

In addition, using the USDA guidelines for sludges suitable for land application, we determined that hot-acid treatment is primarily useful in decreasing the metal levels of sludges which are higher than the USDA recommended levels. This increases the marketability of the sludge.

The major drawbacks of the hot-acid process are the sludge's apparently poor dewaterability following treatment and the associated solubilization of nutrients along with heavy metals. Only 25-percent of the solids were recovered by centrifugation, with no flocculating aids. Aids, such as non-ionic polymer, that would not be affected by the sludge's low pH or affect the soluble metals, might enable successful dewatering. Further investigation should be conducted to assess dewaterability.

Walden's results also showed nutrient solubilizations between about 15 and 40 percent for organics and nitrogen. Although Walden did not measure phosphorus, other studies have shown relatively high phosphorus solubilizations by acid addition. Nutrient solubilization detracts from the fertilizer value of the final sludge product when land applied.

The degrees of solubilization for metals are primarily dependent on the particular metal's chemical characteristics, the type of sludge being treated, and the acid dosage. Walden recommends using 20-percent (dry sludge solids basis) concentrated sulfuric acid dosage for metals removal. However, dosages up to about 30-percent are needed to bring about significant solubilization of copper. At 20-percent acid usage, Walden's tests resulted in average metal solubilizations of 85 percent for cadmium, 80 percent for zinc, 80 percent for nickel, 24 percent for chromium, and zero percent for copper.

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Capital costs and net unit costs of hot-acid treatment are high when compared to conventional sludge treatment systems.

	Cost per dry ton	
	2-mgd plant	20-mgd plant
Hot-Acid Treatment	$440	$140
Anaerobic Digestion	$114	$ 42

These costs do not include dewatering of the hot-acid sludge or anaerobically digested sludge, because successful dewatering performance criteria are not available for hot-acid sludge. Actual costs may be significantly higher.

Costs of hot-acid treatment should also be compared to other methods to remove or control heavy metals. One method is source control; that is, by removing heavy metals from contributing wastewater flows before the flows reach the treatment plant. Source control can be expensive. For example, in New York City, the source control costs for industry alone would be about four times greater than hot-acid treatment of sludge. Therefore, hot-acid treatment appears economically promising when compared to source control costs.

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SECTION 3

RESEARCH ON SLUDGE ACIDIFICATION

RESEARCH BY WALDEN

The Walden investigations included three series of bench-scale tests investigating solubilization and separation, bench and full-scale tests on dewatering, development of specifications for pilot tests, and economic analysis.

The first test series was aimed at measuring solid-liquid separation of municipal sludge following hot-acid treatment. The primary process variables pH, temperature, and time were analyzed within the ranges of pH 2 to 3, 80°C to 95°C, and 10 to 60 minutes. Four sludges were used for these tests: two waste activated sludges and two combined primary and waste-activated sludges.

The first test series determined that the optimum process variable values for solid-liquid separation-rate are pH 2.5 (achieved with 7 to 10 percent sulfuric acid dosage on dry sludge solids basis) and 95°C for the sludges tested. Using zinc, pH proved to be the only process variable affecting solubilization. Separation rate was not significantly affected by time greater than 10 minutes. In addition, hot-acid treatment completely destroyed pathogens.

The second series of tests compared the hot-acid process to thermal treatment and chemical conditioning. Hot-acid treatment was less effective than thermal treatment, but about as effective as chemical conditioning for solid-liquid separation. The hot-acid process solubilized much greater percentages of metals and significantly lesser percentages of chemical oxygen demand and nitrogen than thermal treatment. These tests were conducted with waste activated sludge.

The third series of tests (also with waste activated sludge) was aimed at determining and optimizing process variables for solubilizing several heavy metals. Walden selected a concentrated sulfuric acid dosage of 20 percent of dry sludge solids as optimum for solubilizing most metals. However, copper required greater than 30-percent acid usage to effect 80-percent solubilization. Optimum temperature and time were found to be 95°C and 60 minutes.

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Bench and pilot-scale centrifuge tests were conducted to specify full-scale dewatering equipment for the process. Although good cake solids were obtained, percent recovery of solids was very poor.

Finally, Walden prepared pilot-plant equipment specifications and economic analyses of the hot-acid process for full-scale treatment systems. The costs were based on treating 3-percent solids sludge at various acid dosages, depending on whether solid-liquid separation or metal solubilization optimization was desired. Walden then compared the costs with those of other sludge stabilization/conditioning processes.

RESEARCH BY OTHERS

Research aimed at treating sludge for heavy metals removal has been conducted by several individuals and organizations over the past decade. The major parameters analyzed have been the pH and temperature of the sludge, based on the knowledge of the solubility characteristics of the metals.

In the early 1970s the Barber-Colman Company developed the "Puretec/Wetox" process for this purpose. The process is essentially wastewater sludge treatment by wet oxidation under mildly acidic conditions. Process parameters are acid addition to a pH of about 3.0, followed by wet oxidation at a temperature of 450°F and pressure of 600 psi for about 40 minutes. The process results in destruction of between 75 and 85 percent of influent COD, conversion of nitrogen compounds to ammonia, and solubilization of heavy metals. Fassell, (1974), stated that "with economically practical levels of sulfuric acid additions, copper, zinc and cadmium are solubilized while lead and silver remain in the insoluble residue...". However, due to the quite large material costs involved and technology associated with the high temperature and pressure process in a corrosive acid environment, Barber-Colman discontinued its undertaking of the process.

In the mid-1970s, research was conducted by Oliver and Carey (1976) to assess the economics associated with the solubilization and extraction of metals from digested sludge. Acid addition to lower the sludge pH to about 1.5 was found to achieve the maximum solubilization possible of most metals. Below this pH, no additional solubilization of metals resulted. For eight different sludges tested at a pH of 1.5, solubilizations varied between 24 and 87 percent for cadmium, 46 and 88 percent for iron, 58 and 98 percent for nickel, and 53 and 93 percent for zinc. Their studies concluded, however, that the removal of heavy metals from wet sludge to reduce its toxicity does not appear to be economically feasible.

Studies by Scott and Horlings (1975) involved extracting and recovering phosphates and heavy metals from digested sludges by acid addition. Acid requirements were measured stoichiometrically, based on solubilizing the cadmium, iron, aluminum, and zinc ions in the sludge. "Excess" acid was also added to account for additional unknown organic and inorganic acid

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usage ions in the sludge. This produced a pH of 1.5 or less for all tests conducted.

A reaction time of about 15 minutes was allowed after acid addition, concurrent with or followed by heating to boiling and then immediate filtering. Sodium or calcium hydroxide solutions were then added to the extract solutions to precipitate metals and phosphate ions.

Sulfuric acid was shown to be clearly advantageous to nitric, perchloric, and hydrochloric acids because of its low cost, its ability to remove calcium as calcium sulfate precipitate when neutralized, and its improvement in filterability. Also, it was shown that, by controlling pH, iron and aluminum can be precipitated first (as phosphates), followed by most of the remaining metals.

Hayes et al (1980) investigated the solubilization of heavy metals in relation to the type of sludge treatment prior to acidification. Using sludge produced from an experimental full-scale autoheated thermophilic aerobic digestion system (ATAD), the authors measured the solubilization of several metals upon acidification for 24 hours at pH 2. Identical tests were also performed on raw and anaerobic sludges. Temperatures of the aerobic, raw, and anaerobic sludges were 55°C, 25°C, and 35°C, respectively. In every case, except for chromium, better metals solubilization was obtained from the ATAD sludge. Chromium was solubilized to about the same degree for each sludge type.

The findings of these tests are explained by Hayes et al to be a function of the type of biological treatment of the sludge. Specifically, aerobic sludge treatment raises the oxidation reduction potential (ORP) of the sludge, which effectively transforms inorganic metal complexes from their natural sulfide form to carbonate, phosphate or hydroxide form. Then, upon acidification, the new metal complex is more readily converted to its soluble ionic form. The authors note that, in raw or anaerobic sludges, metal sulfides are the predominant inorganic metal complex. The similarity in chromium solubilization for the three sludge types is explained by the predominance of chrominum hydroxide in raw and anaerobic sludges as well as in aerobic sludges.

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SECTION 4

EVALUATION OF HOT-ACID TREATMENT TECHNOLOGY

In our study of hot-acid treatment, we evaluated certain process parameters with regard to their impact on the overall effectiveness of heavy metals removal from sludge. This section of the report discusses these parameters in detail by examining the results obtained through Walden's experiments. Of primary importance are the expected metal solubilizations and the solubilizations of other sludge constituents. Also discussed below is the ability of hot-acid treatment to stabilize sludge and condition sludge for subsequent dewatering.

SOLUBILIZATION OF HEAVY METALS

Walden performed bench-scale tests to optimize the hot-acid process with specific regard to the degree of solubilization of cadmium, zinc, nickle, chromium, and copper. The variables tested were type of sludge digestion apparatus, stirring speed, digestion time, acid usage, and sequence of acid and heat addition prior to digestion. The digestion temperature for all tests was 95°C which had been previously determined by Walden to be more effective than lower temperatures with regard to sludge dewatering. Waste activated sludge from several wastewater treatment plants was used for these particular tests.

Their report states the following conditions as being most conducive to heavy metals solubilization:

- rapid stirring in digester, primarily to provide homogeneity and effective heat transfer (600 rpm as opposed to 60 rpm)
- acid addition before heat addition
- digestion retention time of 60 minutes as opposed to 30 minutes.

The variable found to most directly influence the degree of metals solubilization was the amount of sulfuric acid added. Since cadmium is commonly the metal of greatest environmental concern, much of Walden's experimentation was with this element. A general trend of increasing cadmium solubilization with decreasing pH was determined, although results were scattered: test results showed that at a pH of greater than 2.5, there was

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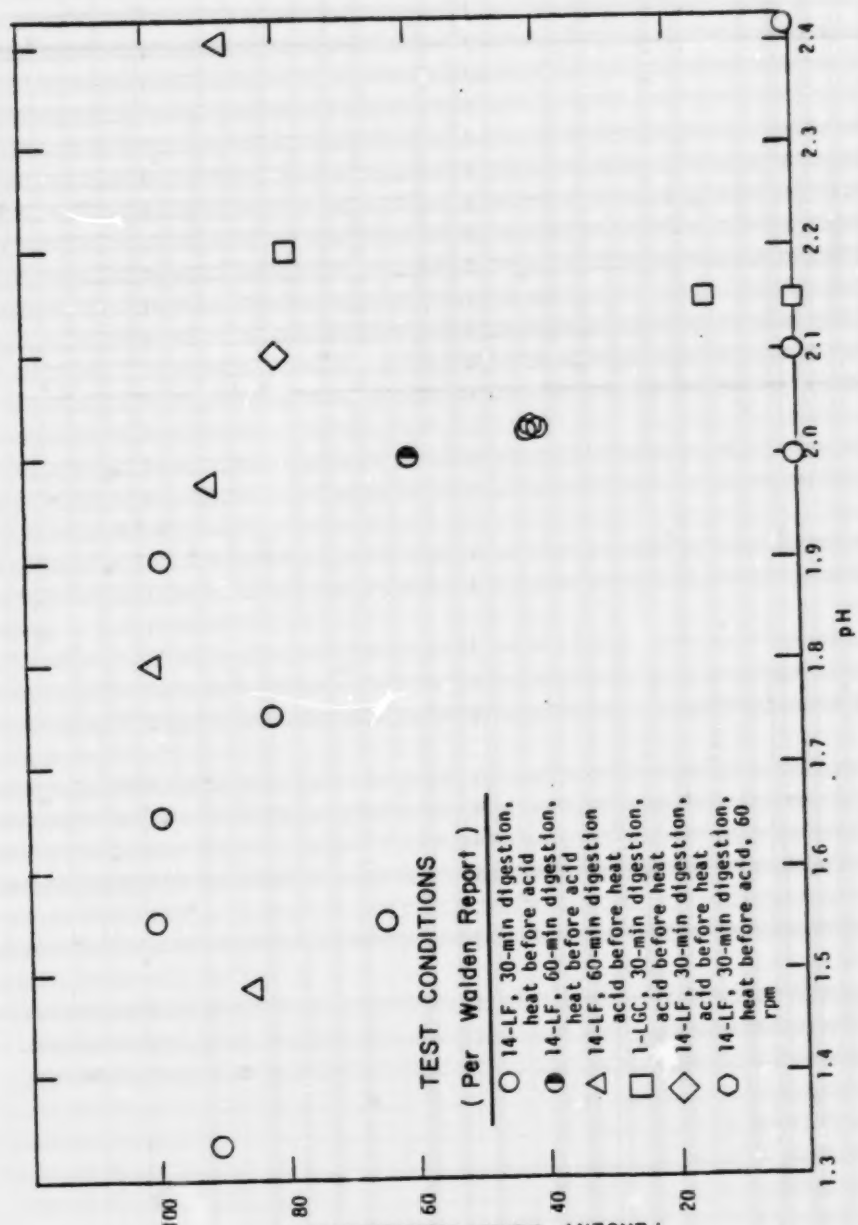

FIG. 1 Cadmium solubilization as a function of pH.
(from Walden Report, Fig. 36)

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essentially no cadmium solubilization; at a pH between 2.0 and 2.5 widely scattered results occurred (as shown in Figure 1); and at a pH less than 2.0 cadmium solubilization varied between about 60 and 100 percent.

A more accurate correlation than with pH was found between metals solubilization and amount of acid added per dry sludge solids, shown in Figure 2 for cadmium. This figure shows the data points, a band to show the scatter, and a curve drawn by eye to fit the points. Walden used two straight-line segments to fit the data. We think that a continuous curve fits the data somewhat better.

Included on the figures are the test conditions which produced each data point. The two digestion units used were a 14-liter fermenter (14-LF) and a one-litre graduated cylinder (1-LGC).

In examining the data represented by these figures, Walden looked for the "knee" in the curve, where there was diminishing benefit with increased acid addition. This dosage was about 20 percent acid addition and was recommended for full-scale application. (See the dotted line on Figure 2 for illustration.) Walden used all the data points to obtain this estimate.

To establish the average metal solubilizations, however, Walden used only the "preferred operating points" (illustrated by the symbol △). These preferred operating points were those data points corresponding to the test conditions which produced the optimum metal solubilizations. The optimum solubilization for cadmium (about 92 percent) is shown by the dashed line in Figure 2. This solubilization requires about 28-percent acid addition.

Similar relationships were determined by Walden for zinc, nickel, chromium and copper. Table 1 summarizes the expected solubilizations of all these metals at both optimum and 20-percent acid usage conditions. The table shows that an average of about 28-percent acid usage is required to produce the optimum metal solubilizations, as listed. Therefore, we have used a range of 20 to 30-percent acid usage for evaluation.

Lead is not included in Table 1, because it was not part of Walden's metal optimization tests. Walden had previously measured its solubility, however, for waste activated sludge from two wastewater treatment plants (Brockton, MA and Milwaukee WI). These previous test were performed to compare the solubilization of sludge constituents by hot-acid treatment and by thermal treatment. The hot-acid treatment conditions used were a pH of 2.5 (approximately 7 to 10 percent acid usage), 10 minute digestion time and 95°C. The resulting lead solubilizations were 10 percent and zero percent for Brockton and Milwaukee waste activated sludges, respectively. For comparison, corresponding chromium solubilizations were 7 percent and 1.3 percent for the two sludges, which is considerably less than 24-percent solubilization shown in Table 1 for 20-percent acid usage. However, these solubilizations are not directly applicable to the values contained in Table 1 because the treatment conditions are considerably different, and lead and chromium do not have the same solubility characteristics. Therefore, lead solubilization cannot be assessed based only on Walden's

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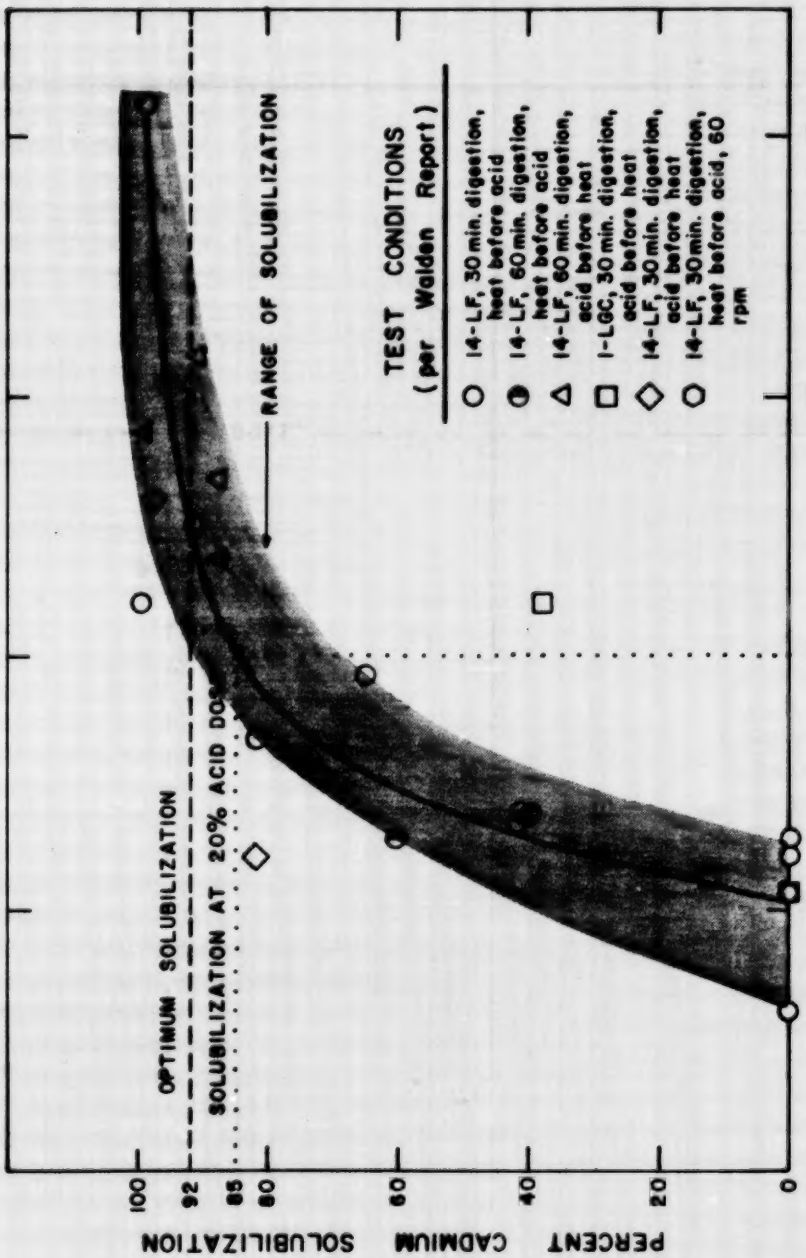

FIG. 2 CADMIUM SOLUBILIZATION AS A FUNCTION OF ACID USAGE

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TABLE 1. SUMMARY OF METAL SOLUBILIZATIONS

Heavy Metal Sludge Constituent	(1) Average Solubilization at 20-Percent Acid Usage (%)	(2) Solubilization, Acid Usage, and pH at Optimum Solubilization Conditions					
		Averages			Ranges		
		Solubilization (%)	(2) Acid Usage (%)	pH	Solubilization (%)	(3) Acid Usage (%)	(4) pH
Cadmium	85	92	28	1.87	88 - 100	24-32	1.47-2.40
Zinc	80	92	28.5	1.85	82 - 100	24-32	1.47-2.40
Nickel	80	84	28.5	1.85	73 - 100	24-32	1.47-2.40
Chromium	24	53	28.5	1.85	42 - 80	24-32	1.47-2.40
Copper	--	53	28.5	1.85	3 - 82	24-32	1.47-2.40

(1) From solubilization data using all data points.

(2) From solubilization data using only data points corresponding to optimum metal solubilization test conditions.

(3) Acid usage is expressed as a percentage of dry sludge solids.

(4) pH range is based on the averages of hydrogen ion concentrations in Walden's tests.

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investigation. Other experiments (Oliver and Carey, 1976) have indicated the low solubility of lead, especially as lead sulfate, the product of sulfuric acid addition. Therefore, it appears that low solubilization of lead can be expected by the hot-acid process.

The Walden solubilization optimization tests were limited to waste activitated sludge. The feasibility of applying the solubilization data to primary or other sludges is discussed later in this report.

As Figure 1 indicates, metal solubilization increases with increasing acid addition. While previous investigations support this relationship, the required acid usage to provide certain degrees of metal solubilizations necessarily varies with each metal and with each sludge.

SOLUBILIZATION OF SOLIDS, ORGANICS, NITROGEN AND PHOSPHORUS

The solubilization of other sludge constituents must also be considered. Specificially, acid effects on the solids, organics, and major nutrients have a large impact on the process' success and the degree of sidestream treatment which must be provided to treat the solubilized constituents. Especially in view of the potential use of hot-acid treated sludge for agricultural land application, nitrogen and phosphorus solubilizations must be minimized, as well as solids and organic content solubilizations.

In Walden's metal solubilization optimization tests, solids, COD, and TKN were measured. Phosphorus was not measured in these tests, although in other Walden tests a pH of 2.5 and 10-minute digestion at 95°C, phosphorus measurements indicated 20 and 45-percent solubilizations for Brockton and Milwaukee waste activated sludges, respectively. The phosphorus tests' acid usages were only about 7-10 percent (pH 2.5) which is not as high as the range used in the metals optimization tests. Therefore, it can be estimated that higher acid usage would result in higher phosphorus solubilizations. This assumption is substantiated by other experimentation by Oliver and Carey (1976) in which phosphorus was solubilized from 21 to 98 percent in eight different digested sludges at a pH of 1.5 (the median solubilization was 90 percent; the mean solubilization was 76 percent).

For solids, organics, and nitrogen, optimum solubilizations were reported by Walden using the "preferred operating points", as previously explained. For solids and organics, these solubilizations correspond to an acid usage of 20 percent. However, all data points for nitrogen solubilization are greater than the 20-percent acid usage level, and Walden estimates an average of 28-percent TKN solubilization. Also, Walden's data show that solids and organics solubilizations do not significantly increase at acid dosages greater than about 20 percent.

Table 2 summarizes the solubilizations which can be expected with hot-acid treatment for these constituents. Although 29-percent acid usage is listed as the optimum test condition, about the same solubilizations result from

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TABLE 2. SUMMARY OF SOLIDS, ORGANICS, & NITROGEN SOLUBILIZATIONS

(1) Solubilization, Acid Usage, and pH at Optimum Solubilization Conditions

	Averages			Ranges		
Sludge Constituent	Solubilization (%)	(2)Acid Usage (%)	pH	Solubilization (%)	(2)Acid Usage (%)	(3)pH
Solids	24	29	1.75	19 - 28	24-32	1.47-1.96
Organics (COD)	16	29	1.75	13 - 19	24-32	1.47-1.96
Nitrogen (TKN)	28	29	1.75	17 - 42	24-32	1.47-1.96

(1) From solubilization data using only data points corresponding to optimum metal solubilization test conditions.

(2) Acid usage is expressed as a percentage of dry sludge solids.

(3) pH range is based on the average of hydrogen ion concentrations in Walden's tests.

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20-percent acid usage, as explained above. These values are useful in evaluating the final sludge product, required sidestream treatment, and costs in full-scale applications of the process.

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SOLIDS SEPARATION

Walden's first series of experiments were aimed at optimizing the hot-acid treatment conditions with respect to solids separation following hot-acid digestion. It was determined that the optimum acid usage for solids separation was between 7 and 10 percent, about one-half the amount subsequently determined to be required for metals solubilization. Solids separation efficiency decreased above and below the 7 to 10-percent range. This was especially true at detention times less than 60 minutes. Walden reported the effects of hot-acid treatment on solids separation at the optimum conditions for separation. Solids separation tests conditions also included 2.5-percent sludge solids concentration and 10-minute digestion time.

With respect to solids-separation processes, three techniques were compared by bench-scale tests conducted in the optimum acid dose range (7 to 10 percent): sedimentation, filtration and centrifugation. Even in the range of optimum pH for separation, sedimentation following hot-acid treatment was found to be inadequate in producing effective solids separation. With regard to filtration, testing showed that hot-acid treatment is about equivalent to chemical conditioning, but that thermal conditioning is superior. The third technique tested, centrifugation, provided the most effective solids separation of the three techniques tested following hot-acid treatment.

Although these comparisons are valid under the optimum conditions for separation, solids separation characteristics under the recommended metals solubilization conditions (with greater acid dosage) should also be assessed in comparison to chemical and thermal conditioning, for proper evaluation of the hot-acid process.

Although centrifugation proved to be more effective than sedimentation or filtration on hot-acid treated sludge (10-percent sulfuric acid dosage), and more effective for hot-acid treated sludge than for chemically conditioned sludge, full-scale centrifugation experiments subsequently conducted at Bird Machine Company on sludge with 20-percent acid dose indicated very poor solids recovery. Bird's tests resulted in an average 27-percent solids cake, but only 25-percent solids recovery, in four test runs. Bird's solids recovery data indicate that hot-acid treatment alone is not sufficient to effectively condition waste activated sludge for dewatering by centrifuge. Dewaterability of hot-acid treated primary sludge, or combined primary and waste activated sludge, was not evaluated. Based on Bird's full-scale test results, dewatering of hot-acid treated sludge appears to be a major problem in the system's feasibility.

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SLUDGE TYPE AND CONCENTRATION

The metals solubilization optimization tests performed by Walden used only raw thickened waste activated sludge. For this reason, the results obtained from the metals optimization tests (Table 1) should not be directly applied to primary sludges alone or in combination with waste activated sludge. Further optimizations testing needs to be performed on primary sludges, and on mixtures of primary and waste activated sludges. This is especially true considering that primary sludges remove relatively high percentages of metals entering wastewater treatment plants. Also, although Walden initially intended hot-acid treatment as a stabilization process as well as a metal-removing process, biological digestion should be tested for its affect on metals removal.

Walden found that the solids concentration of the sludge affects acid usage because of the acid demand of the liquid versus that of the insoluble constituents. The Walden test results indicate that the sludge's liquid fraction exerts an acid demand greater than the solid fraction. Studies by Scott and Horling (1976) suggest that a maximum of 11-percent solids should be used for fluid mixing (including acid volume). In general, the optimum condition is to maximize solids concentration without sacrificing mixing capability, in order to decrease the acid demand created by the sludge's liquid fraction. In full-scale application this would be done by providing thickening to at least waste activated sludge, as Walden recommends, and possibly to primary sludges, before hot-acid treatment. An additional constraint is that heat transfer efficiency is decreased through the system's heat exchanger at higher solids concentrations. For this study, a combined thickened primary and waste activated sludge at 5-percent solids is used to evaluate equipment requirements and costs.

ACID TYPE AND CONCENTRATION

Sulfuric acid is recommended by Walden for use in the hot-acid process. Other acids were evaluated by Oliver and Cary (1976). Their results showed that sulfuric, hydrochloric, and nitric acids all produced similar metals solubilizations. They eliminated nitric acid because of its high cost and nitrogen content, and concluded that sulfuric or hydrochloric acid could be successfully used. Since sulfuric acid is generally less expensive than hydrochloric acid, sulfuric acid is used in our evaluation.

Sulfuric acid concentration prior to mixing with sludge was shown by Walden to have negligible affect on sludge settling, except at high dilutions ($75:25/H_2O:H_2SO_4$), where settling was initially retarded. Concentrated sulfuric acid also reportedly resulted in 20-percent less total organic carbon (TOC) solubilization than dilute sulfuric acid. Explanation of this organics behavior was not explained by Walden; rather, it was expected that greater organics solubilization would accompany the use of concentrated acid. Concentrated sulfuric acid addition, as recommended by Walden for full-scale application, is preferred for handling and storage reasons.

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PATHOGEN REDUCTION

Any proposed sludge stabilization process must be effective in pathogen reduction. Bacterial assays of fecal streptococcus and fecal coliform in both waste activated sludge and combined primary plus waste activated sludge before and after hot-acid treatment revealed almost complete bacteria destruction, as reported by Walden. The hot-acid treatment conditions tested were 10-minutes digestion time at 95°C at an acid usage of 10 percent. Based on these data, and especially considering that these conditions provide less hot-acid treatment than recommended for metals solubilization, the hot-acid process, when operated to solubilize metals at 20-percent acid usage, can be expected to effectively decrease pathogens. Table 3 presents bacteria assay data for both raw and hot-acid treated sludges taken from Walden's report.

Table 3. BACTERIAL ASSAYS FOR RAW AND HOT-ACID-TREATED SLUDGES*

Sludge Sample	Fecal Streptococcus, counts/100ml	Fecal Coliform counts/100 ml
Brockton WAS		
Raw	--	9.6×10^7
Hot-acid treated	--	<100
Brockton primary plus WAS		
Raw	3.3×10^6	3.5×10^7
Hot-acid treated	<100	<100
Fitchburg WAS		
Raw	--	4.2×10^8
Hot-acid treated	--	<100
Fitchburg primary plus WAS		
Raw	--	2.8×10^8
Hot-acid treated	--	<100

* from Walden report.

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SECTION 5

EFFECTS OF HOT-ACID TREATMENT ON SLUDGE UTILIZATION

Following dewatering of the hot-acid sludge and pH neutralization of the sludge cake, a sludge product is available which has significantly decreased heavy metal concentrations. The organic, nitrogen, and phosphorus content of the sludge, although reduced by solubilization, makes the sludge a useful soil conditioner.

This section of the report examines the quality of the hot-acid treated sludge product and its utilization benefits compared to sludge without hot-acid treatment. To do this it has been assumed that successful hot-acid treatment is achieved with optimum metal solubilizations at 20- to 30-percent acid usage, as shown in Table 1. The dewatering process is assumed to yield 85-percent solids recovery and 20-percent solids cake.

LAND APPLICATION RATE

Federal regulations (USEPA, 1979) stipulate that the annual application of cadmium from sludge cannot exceed 0.5 kilograms per hectare (kg/ha) on land used for production of tobacco, leafy vegetables or root crops grown for human consumption. It is also stipulated that this same application rate will become effective for other food-chain crops beginning January 1, 1987. Cadmium-bearing sludge is therefore limited in regard to its application rate for a given land area. Conversely, the amount of land area required to dispose of such sludge is dependent upon the cadmium level in the sludge.

To illustrate this point, let us look at how the hot-acid process would affect the land requirements for application of sludge from Milwaukee, WI. Table 4 presents the heavy metal levels in Milwaukee sludge before and after hot-acid treatment, as well as the optimum metal solubilization and removal efficiencies achieved. Actual metal removals are shown to be somewhat less than metal solubilizations. This is based on the assumed dewatering performance. The soluble metal content of the liquid fraction of the sludge cake adds to the metal content of the sludge cake solids. Thus, the sludge product's metal concentration is actually higher (on dry basis) than the non-solubilized metal content of the cake solids. The treated sludge metal levels are based on the percent removals listed.

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TABLE 4

MILWAUKEE SLUDGE HEAVY METAL CONCENTRATIONS

BEFORE AND AFTER HOT - ACID TREATMENT

HEAVY METAL	RAW SLUDGE[1] mg/kg	HOT - ACID TREATMENT		TREATED SLUDGE mg/kg
		%SOLUBILIZATION	%REMOVAL[2]	
Cadmium	126	92	73	34
Chromium	6,255	53	42	3,630
Copper	350	53	42	203
Nickel	115	84	66	39
Zinc	1,115	92	73	301

[1] Metropolitan Sewerage District Data, 1979.

[2] Based on 5-percent raw sludge solids concentration, 85-percent solids recovery by dewatering, and 20-percent solids sludge cake.

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Using the maximum cadmium (Cd) application rate of 0.5 kg/ha-yr, the raw sludge containing 126-mg/kg Cd can be land applied at an annual rate of about 4,000 kilograms of sludge per hectare (3,600 lb/acre). After hot-acid treatment, however, the treated sludge contains only 34-mg/kg Cd, which can be land applied at an annual rate of about 14,700 kilograms of sludge per hectare (13,100 lb/acre). Thus the raw sludge requires approximately 3.7 times more land area for disposal than the hot-acid treated sludge. Using these before-and-after land application rates for a 20-mgd wastewater treatment plant producing 20 tpd (dry) of sludge results in the following land area requirements: 4,050 acres for raw sludge application and 1,110 acres for treated sludge application. This would result in some economic benefits associated with operating and sludge transportation costs for the hot-acid treated sludge, and is especially valueble if there is a limited quantity of available land. The major advantage is the provision of a low metal content sludge, which cannot be readily defined in terms of dollars. Economic benefits are discussed further in Section 7.

SLUDGE PRODUCT QUALITY

The only Federal regulatory requirement at present for sludge applied to land is the aforementioned Federal regulation limiting cadmium application rate and the cumulative cadmium loading per acre on soil used to grow crops in the human food chain. This requirement has been instituted to protect human health. It does not protect the crop-growing potential of the soil. Other metals, particularly copper, nickel, and zinc, individually or in combination, can build up in soil to levels toxic to plants. To assure the long-term utility of the soil, the USDA has recommended approximate upper limits of heavy metal concentrations in sludges suitable for land application.

The interim facilities plan for New York City proposed that the USDA recommendation be used as guidelines as to whether a sludge could be distributed to private users, and decided that sludge could be used provided it met the USDA guidelines 90 percent of the time. It is interesting to examine the suitability of New York City sludges according to the standard and observe the effect of the hot-acid treatment on sludge acceptability for private use. The results of the comparison are presented in Table 5.

Examination of the last column in Table 5 shows that originally no plants met the USDA recommendations. The use of the hot acid process actually made the sludge of only one plant suitable. However, six plants were high only in copper. Some of these plants were greatly reduced in nickel, which allows a higher loading of the other toxic elements without potential harm to the soil.

The New York City sludges are higher in metals than most municipal sludges. If appears that the hot-acid process could bring many sludges to suitable levels for land application if the economics of the situation are suitable.

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TABLE 5

HEAVY METAL CONCENTRATIONS IN SLUDGE FROM NEW YORK CITY WASTEWATER TREATMENT PLANTS[1]
BEFORE AND AFTER HOT-ACID TREATMENT (mg/kg of dry solids)

		Cadmium	Chromium	Copper	Nickel	Zinc	Metals which exceed USDA Guidelines
USDA Guidelines		25	1000	1000	200	2500	
NYC Plants							
1	Raw	16	1240	1278	89	1188	Cr, Cu
	Treated	4.5	724	741	30	321	None
2	Raw	44	1300	2218	328	2608	Cd, Cr, Cu, Ni, Zn
	Treated	12	754	1290	112	704	Cu
3	Raw	540	7600	3200	320	5760	Cd, Cr, Cu, Ni, Zn
	Treated	146	4410	1860	109	1560	Cd, Cr, Cu
4	Raw	239	3600	2220	290	3340	Cd, Cr, Cu, Ni, Zn
	Treated	65	928	1290	99	902	Cd, Cu
5	Raw	15	658	2370	240	2578	Cu, Ni, Zn
	Treated	4.0	382	1370	82	696	Cu
6	Raw	33	828	2976	360	3280	Cd, Cu, Ni, Zn
	Treated	9.0	480	1730	122	886	None
7	Raw	132	3200	2120	1840	3160	Cd, Cr, Cu, Ni, Zn
	Treated	36	1860	1230	626	853	Cd, Cr, Cu, Ni
8	Raw	60	1010	2410	310	3698	Cd, Cr, Cu, Ni, Zn
	Treated	16	586	1400	105	998	Cu
9	Raw	200	3280	3018	360	4880	Cd, Cr, Cu, Ni, Zn
	Treated	54	1900	1750	122	1320	Cd, Cr, Cu
10	Raw	64	1680	1957	70	2100	Cd, Cr, Cu
	Treated	17	974	1140	24	567	Cu
11	Raw	24	320	1740	200	2500	Cu
	Treated	6.5	215	1010	68	675	None

[1] Camp, Dresser and McKee data, 1978.

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SECTION 6

HOT-ACID TREATMENT FACILITIES

HOT-ACID TREATMENT SYSTEM

Figure 3 presents the flow scheme for hot-acid treatment of sludge. Some of the components differ from those described by Walden. In those cases, the reasons are discussed later. Thickened primary and waste activated sludge is drawn from the sludge holding tank through a grinder and into an acid-sludge mixing tank for acidification. The acid sludge is pumped through a heat exchanger into a reactor/digester. Steam is injected into the reactor/digester to bring the acid-sludge to just under boiling temperature. Walden's tests indicate an optimum retention time within the reactor/digester of about 60 minutes for metals solubilization. However, decreased dewaterability and increased organics and nitrogen solubilizations occur with 60-minutes retention time. Therefore, 30 minutes was recommended by Walden as the optimum time and is used in our evaluation.

The hot-acid treated sludge is then passed back through the heat exchanger and into the acid-sludge holding tank. Off-gases from the holding tank are scrubbed and exhausted. The acid-sludge is next dewatered to produce a sludge cake having low metals concentrations and a sidestream having high metals concentrations. The sidestream (Figure 4) is treated with lime and coagulant to precipitate insoluble metal hydroxides which are subsequently settled in the clarifier. Clarified supernatant is recycled to the head of the plant, and settled metal hydroxide sludge is dewatered and disposed to a secure landfill.

The acid-sludge cake resulting from the initial solids-separation process is neutralized by hydrated lime addition using screw conveyors, and is transported and is available for utilization.

SLUDGE STORAGE AND PUMPING

Sludge storage (holding) assists in operating the hot-acid system. Without storage, schedules and loading rates for the acid system would have to match those for thickening equipment. About 4 hours' storage at peak sludge flow rate should be adequate. The tanks are mixed to ensure a homogeneous mixture of the primary and waste activated sludges. Sludge

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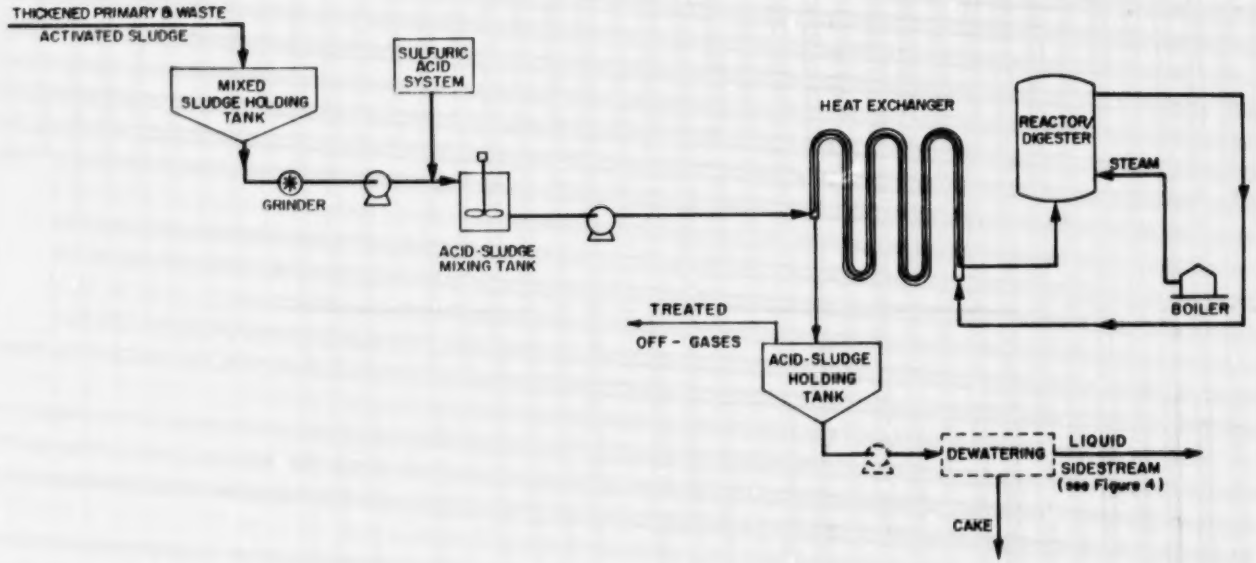

FIG. 3 FACILITIES FOR HOT-ACID TREATMENT OF SLUDGE

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pumping from the wastewater treatment plant to the holding tanks is not considered in our evaluation, because it is part of the plant itself--common to all sludge handling systems.

In line between the holding tanks and pumps from the holding tanks is a grinder to prevent large materials, which might be contained in the primary sludge, from clogging the downstream heat exchangers.

HOT-ACID PROCESS

Acid Storage, Feed and Mixing

Acid storage and feed facilities should be based on 95-percent concentrated sulfuric acid added to the sludge at a 20-percent dry weight dose, as is recommended in Walden's report. The concentrated acid storage is sized for two weeks' peak capacity. Sludge and acid are mixed in a mixing tank sized to provide a 10-minute peak sludge mixing time.

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Acid-Sludge Heating and Digestion

Following the 10-minute acid mixing, pumps carry the acid-sludge through a heat exchanger and reactor/digester tank and into an acid-sludge holding tank. This system is the major process component of hot-acid treatment.

Walden's report presents a system in which acid-sludge would be pumped through a heat exchanger into a paddle-mixed digestion tank. Steam-heated coils within the tank would bring the acid-sludge temperature to 95°C. From the digestion tanks, the sludge would be pumped back through the heat exchanger to a dewatering centrifuge.

The use of internal coils for heating sludge (in digesters) has been virtually abandoned in sludge processing. Sludge tends to cake on the coils and decrease heat transfer. CDM considers existing technology for sludge pasteurizers and heat conditioning units to be a more effective means to provide the required hot-acid treatment. In these systems, positive displacement pumps circulate sludge through a heat exchanger to a reactor section. Direct steam addition to the reactor raises the temperature to above that which the heat exchanger provides. Also included with the heat exchanger and digestion unit is a solvent wash system for periodic cleansing of the system. Standby pumps and grinders are also provided in case of equipment failure.

Acid-Sludge Storage

After the digested hot-acid sludge is passed back through the heat exchanger, to heat the incoming acid-sludge, it is carried into sludge holding tanks prior to being dewatered. The holding tanks are equipped with a wet scrubber system which is used for drawn-off hot-acid sludge

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vapors. Also, a slow mixer is included to provide a homogeneous sludge feed to the dewatering process. Although this type of holding tank is commonly used as a decant tank following heat conditioning, hot-acid treated sludge does not exhibit good settling characteristics. The holding tank is, therefore, used primarily for providing short-term storage and flow equalization to the dewatering process, and is sized for 4 hours at peak sludge flow.

DEWATERING

From the hot-acid treated sludge holding tank, sludge is pumped to the dewatering process, where the liquid portion of the sludge containing solubilized metals is separated from the relatively metal-free sludge solids. As discussed earlier, large-scale centrifugation test performance data indicated that hot-acid treatment alone is not sufficient to effectively condition waste activated sludge for dewatering by continuous solid-bowl centrifuge. Moreover, the addition of lime to aid dewatering is not feasible because it would likely cause the dissolved metals to precipitate. Although the addition of non-ionic polymer would probably increase the solids recovery, the actual solids recovery and solids loading rate, among other dewatering design parameters, cannot be accurately predicted without sufficient test data.

Because the performance evaluation of hot-acid sludge dewatering is not possible based on the above tests the dewatering process equipment cannot be thoroughly evaluated and is not included in this report's cost analysis. It must be pointed out, however, that the dewatering process is a necessary step in the overall hot-acid scheme, without which the system's effectiveness is severely limited. Because of the apparently difficult dewatering characteristics of the hot-acid sludge and the necessary corrosion-resistant materials, the dewatering process could become a relatively costly component of the hot-acid treatment system.

Although hot-acid sludge dewatering performance criteria cannot be selected for this report, criteria must be chosen for this study to evaluate the further handling of both the dewatered cake and liquid sidestream. For this reason, values corresponding to efficient dewatering have been chosen. These are: 85-percent solids recovery and 20-percent sludge cake solids content.

SIDESTREAM TREATMENT

The liquid sidestream from the dewatering process is at a pH between 1.5 and 2.5 and contains high concentrations of solubilized heavy metals, in addition to the BOD, COD, and solids solubilized by hot-acid treatment and the solids not captured by the dewatering process. To precipitate the soluble heavy metals, the liquid's pH must be raised to between 8 and 9. Figure 4 presents the flow scheme for treatment of the dewatering sidestreams. The addition of lime to the sidestream, followed by mixing,

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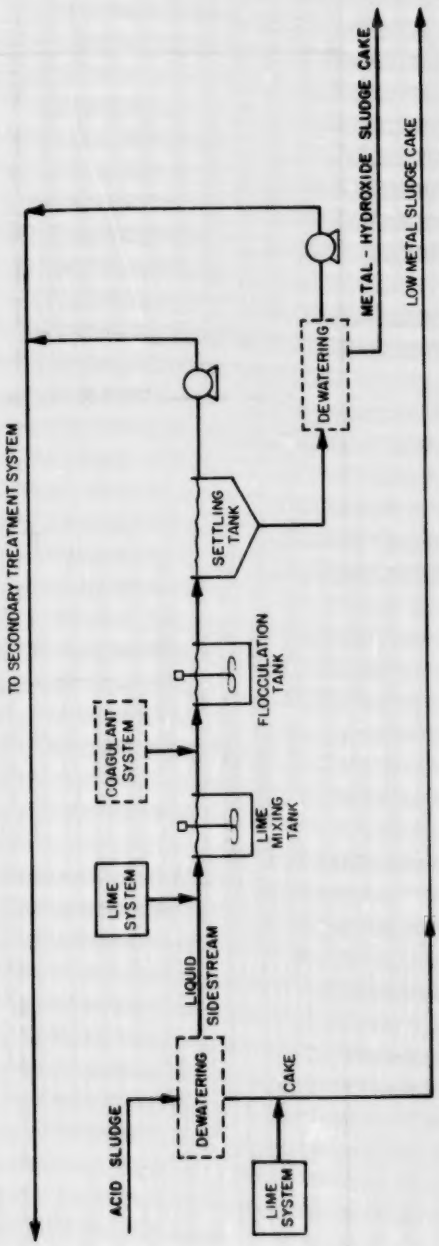

FIG. 4 FACILITIES FOR HANDLING DEWATERING SIDESTREAM

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flocculation, and sedimentation, effectively produces a concentrated metal-hydroxide sludge and clarified supernatant, both at an elevated pH.

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For lime addition, the plant size would dictate the type of lime handling facilities required. Small plants would be able to use hydrated lime delivered in bags, while it may be more advantageous to use quicklime (CaO) in conjunction with slaking equipment for larger plants. In addition to lime, chemical coagulants such as ferric chloride, alum, or polymer may be required to aid flocculation.

Following clarification, the settled metal-hydroxide sludge is dewatered prior to disposal. As is the case with dewatering the hot-acid sludge, expected performance characteristics are unknown and metal-hydroxide sludge dewatering equipment cannot be evaluated. Because this sludge is high in metals content, it must be disposed of in a secure landfill to assure that leaching to groundwater does not occur. Supernatant from the metal-hydroxide sludge dewatering process is pumped back to the head of the plant's secondary treatment system.

Supernatant from the metal-hydroxide sludge settling tank is also pumped back to the head of the plant's secondary system. The high pH of this recycled flow is not significant at such relatively low flows compared to the overall flow of the plant. Its organic content, however, is a significant contribution to the organic load of the plant. For this reason, consideration must be given to the additional plant aeration capacity required to treat the recycled sidestream BOD. The BOD content of the sidestream is both soluble and insoluble, resulting from hot-acid solubilization and solids, respectively. For this study, based on reported COD and solids solubilizations, hot-acid sidestream BOD strength is estimated to be 1500 to 5000 mg/l, approximately one-half of that which results from heat conditioning.

Gases produced by hot-acid digestion may include corrosive acid vapors or other undesirable gases, which would require treatment. Walden's pilot plant specifications include a condenser and carbon adsorption column to treat these gases. Scrubber systems are also considered suitable based on their use in heat conditioning and low pressure oxidation systems.

NEUTRALIZATION OF DEWATERED SLUDGE SOLIDS

Following dewatering of hot-acid treated sludge and prior to utilization or disposal of the cake solids, the low pH of the cake must be raised to acceptable levels. For land application of sludge, the EPA stipulates that the pH of the sludge/soil mixture at the time of application should be 6.5 or higher except for sludges containing cadmium at concentrations of 2 mg/kg (dry weight) or less (USEPA, 1979).

Walden recommends the use of anhydrous ammonia to neutralize the dewatered sludge cake while also increasing its nitrogen content, making the sludge potentially more valuable for land application. Although Walden states the

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possible need to raise the cake's pH as such, its cost is not included in their economic analysis.

Liquid anhydrous ammonia could be used to raise the pH. Its use requires pressurized containment because anhydrous ammonia is gaseous under standard conditions. Mixing the sludge cake and liquid ammonia would also necessarily be under controlled conditions, because of the liquid ammonia's volatile nature.

Hydrated lime (available as a powder) would be more suitable to raise the sludge's pH. It could be mixed with the sludge cake in a screw conveyor. This is being done at Glastonbury and Stamford, CT to lime stabilize sludge cake.

MATERIALS SELECTION

The corrosive nature of heated, acidified sludge requires careful materials selection. Concentrated sulfuric acid can be handled and stored in ordinary carbon steel tanks, piping, and fittings made of copper-bearing steel. Acid sludge is more corrosive than the concentrated acid because of its severe reducing nature. For sludge at about 5-percent solids dosed with acid on a 20-percent dry weight basis, as used in this study, the acid-sludge mixture has about a 1-percent sulfuric acid concentration. Materials which can withstand this solution include glass, ceramics, vitreous tile, carbon, Teflon, fiberglass reinforced polyester (FRP), polyethylene, polypropylene, Hastelloys B and C, and Carpenter 20 stainless steel. FRP is most suitable for this application, with Carpenter 20 stainless steel mixer shafts and impellers.

Higher acid-sludge temperatures increase the corrosiveness of the solution; therefore, the materials selected for the heat exchanger and digester (and piping) must resist the 1-percent sulfuric acid solution at up to 95°C. Carpenter 20 stainless steel, FRP, and Teflon will handle this hot-acid solution. For the heat exchanger and digester equipment and piping, Carpenter 20 stainless steel is most suitable; 300-series stainless steel does not appear to be adequately resistant to acidified sludge at high temperatures.

FRP is most suitable for use as the hot-acid sludge holding tank material, wherein the acid-sludge would be at a temperature of about 35°C. Carpenter 20 stainless steel is required for the dewatered cake conveyance prior to neutralization, while the hydrated lime can be handled by carbon steel storage, mixing, and conveyance equipment. The sidestream-lime mixing tank can be constructed of FRP, with Carpenter 20 stainless steel mixer shafts and impellers, to resist the incoming acidic sidestream. The lime storage and handling do not require special materials. Although the hot-acid-sludge dewatering equipment is not selected in this study, materials selection would need to be carefully analyzed to assure corrosion resistance to the degree that Carpenter 20 stainless steel would assure.

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SECTION 7

ECONOMIC ANALYSIS

In this section, we examine the costs of the hot-acid process and compare them with those for sludge processing alternatives.

Of several environmentally acceptable disposal methods, we chose two to use in cost comparisons with the hot-acid process. One of these is digestion followed by land application. In that case, a metal-laden sludge would have to be applied at a lower rate than one that had received hot-acid treatment. Another alternative is to use pretreatment at the heavy metal sources (such as platers). This pretreatment would decrease the concentration of heavy metals in the wastewater sludges and allow greater flexibility in choosing sludge processing methods.

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BASIS OF COSTS

CDM's evaluation of the hot-acid process includes selection of hot-acid treatment equipment to handle thickened primary and waste activated sludge from two wastewater treatment plants whose capacities are 2 mgd and 20 mgd.

Sludge quantities are based on 1 ton per day of combined primary and waste activated sludge (on dry basis) per million gallons of influent wastewater. Also, primary sludge is assumed to have been thickened to about 6-percent solids content, and waste activated sludge is assumed to have been thickened to about 4-percent solids. The combined sludge percent solids is about 5 percent for equal dry quantities of primary and secondary sludges. For equipment design, a sludge quantity peaking factor of 150 percent has been added. Thus, the peak influent sludge to the hot-acid treatment is 6,000 lb/day for a 2-mgd plant and 60,000 lb/day for a 20-mgd plant. These quantities result in about 15,000 gpd and 150,000 gpd of sludge for the 2-mgd and 20-mgd plants, respectively.

Operation of the treatment systems is assumed to utilize one 8-hr shift per day, five days per week for the 2-mgd plant size, and two 8-hr shifts per day, seven days per week for the 20 mgd plant size. Typical costs associated with treatment plant administration and, to some degree, laboratory work are not included in this analysis because they would be provided under the normal operation of the entire treatment plant.

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As explained in Section 6, the dewatering processes for the hot-acid sludge and precipitated metal-hydroxide sludge cannot be evaluated in this report without reliable performance data. Costs associated with these processes are, therefore, omitted from this cost analysis. Consequently, costs associated with dewatering anaerobically digested sludge have also been omitted, to provide an equal basis for comparison of the two sludge treatment systems. Similarly, costs for sludge transportation and disposal are not included in this study, because they are site-specific. However, sidestream treatment costs for the hot-acid systems are included, based on dewatering performance assumptions discussed in Section 6.

Table 6 presents the criteria used to determine sludge production and costs for each sludge treatment system and size. The capital cost base, operator salary, and electricity cost used are representative of January 1980 costs.

HOT-ACID TREATMENT COSTS

Estimated capital costs for hot-acid treatment at 2-mgd and 20-mgd plants are itemized in Tables 7 and 8 for each equipment item and building. Each item is discussed in Section 6 of this report. Equipment costs are based on information obtained from manufacturers. The cost of each equipment item is presented as a purchased cost and installed cost. The total equipment costs and building costs are presented as amortized annual values in Table 9 for both plant sizes. Annual operating costs are also itemized in Table 9 for labor, maintenance, chemicals, power, and fuel.

Costs for the 2-mgd Plant

Capital Costs. For the 2-mgd hot-acid treatment system, the total equipment cost is about $1,750,000, and the building cost is about $300,000, which is a capital cost of about $2,070,000, or $190,000/yr when amortized. The major cost item is the system's heating and digestion equipment which costs about $1,300,000; about 60 percent of the capital cost.

Operating Costs. The 2-mgd hot-acid treatment system requires two full-time operators for operations and one part-time operator for maintenance for one shift per day, five days per week, including laboratory work. The annual maintenance cost of replacement parts and supplies is based on percentages of equipment capital costs, ranging from 1 to 5 percent, depending on the equipment item. Chemicals required for this plant include 77-gpd to 116-gpd concentrated sulfuric acid, 850-lb/day to 1,200-lb/day hydrated lime for sidestream metal precipitation, and 110-lb/day to 165-lb/day hydrated lime for dewatered acid-sludge cake neutralization. Bagged hydrated lime systems are used for both the sidestream and cake treatment processes. The ranges of acid and lime quantities are based on between 20- and 30-percent acid usage for metal solubilization. Although chemical coagulants would also be required for flocculation within the sidestream metal precipitation process, the specific type and quantity cannot be evaluated in this study and is omitted from this cost analysis for both plants. The estimated

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TABLE 6

CRITERIA USED FOR COST ANALYSIS

Sludge Production	2000 dry pounds sludge per million gallons wastewater treated
Sulfuric Acid Usage	20 to 30 percent of dry sludge solids
Capital Cost Base	3130 (ENR, January 1980)
Capital Cost Amortization	20 years; 7 percent (Equipment) 40 years; 7 percent (Buildings)
Salary	$10.00 per hour (including benefits)
Electricity Cost	$0.06/kwh
No. 2 Fuel Oil Cost	$0.85/gal
Chemical Unit Cost:	
Concentrated Sulfuric Acid	$77 per ton H_2SO_4 delivered
Bagged Hydrated Lime	$125 per ton CaO delivered
Quicklime	$65 per ton CaO delivered

TABLE 7

ESTIMATED HOT-ACID TREATMENT COSTS -- 2 MGD PLANT FLOW

EQUIPMENT ITEM	NUMBER	DESIGN BASIS	UNIT SIZE/CAPACITY	ESTIMATED EQUIPMENT COSTS PURCHASED	INSTALLED
Sludge Holding Tank w/turbine mixer	1	4 hrs. retention time, carbon steel	12,000 gal. 12-ft. dia. x 15-ft. SWD	38,000	57,000
Sludge Pumps	2	Centrifugal	50 gpm, 30-ft. TDH	6,000	16,000
Acid System	1	Sulfuric Acid (concentrated)			
-Storage Tank w/ turbine mixer	1	2 wks., 316 SS tank and mixer	1,200 gal. 5-ft. dia x 9-ft. SWD	8,300	13,000
-Pumps to Day Tank	2	Diaphragm Pump, TFE Diaphragm, 316 SS body	600 gph, 30-ft. TDH	11,000	25,000
-Acid Day Tank	1	316 SS Tank	200 gal. 3-ft. dia x 5-ft. SWD	1,650	3,000
-Acid Feed Pumps	2	Diaphragm Pumps, TFE Diaphragm 316 SS Body	20 gph, 30-ft. TDH	3,800	11,000
-Acid Sludge Mix Tank	1	10-min. FRP tank, Carpenter 20 SS mixer	500 gal. 4-ft. dia x 6-ft. SWD	8,900	13,000
Hot-Acid Process System -Sludge Grinder -Piston-Type Pump -Heat Exchanger -Reactor/Digester -Solvent Cleaning -Steam Generation and Injection -Water Softening -Motor Control Center -Instrumentation	1	This entire system is sized for 80 percent heat recovery through heat exchanger and 30-min. reactor/digester time. It is modelled after a sludge-pasteurization system which utilizes similar equipment components.	50 gpm 80% heat recovery 30-min. digestion	660,000	1,280,000
Hot-Acid Sludge Holding Tank	1	4-hrs. retention FRP tank, SS mixer	12,000 gal. 12-ft. dia. x 15-ft. SWD	38,000	53,000
Sub-Total Costs				775,650	1,471,000

TABLE 7 (continued)

ESTIMATED HOT-ACID TREATMENT COSTS -- 2 MGD PLANT FLOW

EQUIPMENT ITEM	NUMBER	DESIGN BASIS	UNIT SIZE/CAPACITY	ESTIMATED EQUIPMENT COSTS PURCHASED	INSTALLED
Dewatering	-	Not Evaluated (see text p. 30)	---	--	--
Sidestream Treatment					
-Lime Feed System	1	Bagged, hydrated lime storage	800 lbs. lime/day	75,000	158,000
-Lime Mixing Tank w/mixer	1	1 gal/lb lime, FRP tank Carpenter 20 SS mixer, bag lime	500 gal.	8,900	13,000
-Flocculation Tank	1	400 gpd/sf, 20-min. carbon steel	1,000 gal.	8,700	14,000
-Clarifier	1	400 gpd/sf, circular	150 sf, 14-ft. dia x 13-ft. SWD	40,000	62,000
-Supernatant Pumps and Tank	2	Centrifugal, carbon steel tank	250 gpm, 100-ft. TDH 6,000 gal tank	12,000	23,000
-Metal Sludge Dewatering	-	Not Evaluated (see text p. 30)	---	--	--
-Metal Sludge Handling	-	Not Evaluated (see text p. 30)	---	--	--
Sludge Cake Treatment					
-Lime Neutralization	2	Bagged hydrated lime with screw conveyor mixing, Carpenter 20 SS	100 lbs lime/day	12,000	25,000
Sludge Product Handling	-	Not Evaluated (see text p. 30)	---	--	--
Sub-Total Equipment Costs				156,600	295,000
Total Equipment Costs				932,250	1,766,000
Installed Building Cost			3,200 sf	--	300,000
Total Installed Cost				--	2,066,000

TABLE 8

ESTIMATED HOT-ACID TREATMENT COSTS -- 20 MGD PLANT FLOW

EQUIPMENT ITEM	NUMBER	DESIGN BASIS	UNIT SIZE/CAPACITY	ESTIMATED EQUIPMENT COSTS PURCHASED	INSTALLED
Sludge Holding Tank w/two turbine mixers	1	4 hrs. retention, carbon steel	38,000 gal. 15-ft. x 28-ft. x 13-ft. SWD	76,000	116,000
Sludge Pumps	2	Centrifugal	160 gpm, 30-ft. TDH	7,000	18,000
Acid System	1	Sulfuric Acid (concentrated)			
-Storage tank w/turbine mixer	1	2 wks, 316 SS tank and mixer	12,000 gal. 12-ft. dia x 14-ft. SWD	19,800	31,000
-Pumps to Day Tank	2	Centrifugal, 316 SS	50 gpm, 30-ft. TDH	6,000	18,000
-Acid Day Tank	1	316 SS Tank	1,500 gal. 6-ft. dia x 8-ft. SWD	5,500	8,000
-Acid Feed Pumps	2	Diaphragm pumps, TFE diaphragm, 316 SS body	70 gph, 30-ft. TDH	4,200	12,000
-Acid Sludge Mix Tank	1	10-min, FRP tank, Carpenter 20 SS mixer	1,600 gal, 6-ft. dia x 8-ft. SWD	10,000	15,000
Hot-Acid Process System -Sludge Grinder -Piston-type pumps -Heat Exchanger -Reactor/Digester -Solvent Cleaning -Steam Generation and Injection -Water Softening -Motor Control Center -Instrumentation	2	This entire system is sized for 80 percent heat recovery through heat exchanger and 30-minute reactor/digester time. It is modelled after a sludge-pasteurization system which utilizes similar equipment components	88 gpm each 80% heat recovery 30-min. digestion	1,656,000	3,192,000
Hot-Acid Sludge Holding Tank	3	4 hrs. retention, FRP tank, SS mixer	12,000 gal each, 12-ft. dia x 14-ft. SWD	114,000	159,000
Sub-Total Costs				1,898,500	3,569,000

TABLE 8 (continued)

ESTIMATED HOT-ACID TREATMENT COSTS -- 20 MGD PLANT FLOW

EQUIPMENT ITEM	NUMBER	DESIGN BASIS	UNIT SIZE/CAPACITY	ESTIMATED EQUIPMENT COSTS PURCHASED	INSTALLED
Dewatering	-	Not Evaluated (see text p. 30)		--	--
Sidestream Treatment -Lime Feed System	1	Quicklime with slaking equipment	8,000 lbs. lime/day	204,000	429,000
-Lime Mixing Tank w/mixer	1	1 gal/lb lime, FRP tank, Carpenter 20 SS mixer	2,000 gal.	14,500	21,000
-Flocculation Tank w/mixer	1	400 gpd/sf, 20-min, carbon steel	4,000 gal.	19,600	31,000
-Clarifier	1	400 gpd/sf, circular	600 sf, 27-ft. dia. x 13-ft. SWD	60,000	97,000
-Supernatant Pumps and tank	2	Centrifugal, carbon steel tank	500 gpm, 100-ft. TDH 15,000 gal tank	22,200	39,000
-Metal Sludge Dewatering	-	Not Evaluated (see text p. 30)	---	---	---
-Metal Sludge Handling	-	Not Evaluated (see text p. 30)	---	---	---
Sludge Cake Treatment -Lime Neutralization		Bagged hydrated lime with screw conveyor mixing, Carpenter 20 SS		19,200	40,000
Sludge Product Handling	-	Not Evaluated (see text p. 30)	---	---	---
Sub-Total Equipment Costs				339,500	657,000
Total Equipment Costs				2,238,000	4,226,000
Installed Building Cost	-		7,600 sf	---	685,000
Total Installed Cost				---	4,911,000

TABLE 9

ESTIMATED AMORTIZED CAPITAL AND ANNUAL OPERATING COSTS

2-MGD AND 20-MGD PLANT FLOWS

	2-MGD PLANT			20-MGD PLANT		
	CAPITAL COST	AMORTIZED FACTOR	ANNUAL COST	CAPITAL COST	AMORTIZED FACTOR	ANNUAL COST
Installed Equipment	$1,766,000	0.09439	$167,000	$4,226,000	0.09439	$400,000
Installed Building	300,000	0.07501	22,500	685,000	0.07501	52,000
TOTAL AMORTIZED CAPITAL COST			$189,500			$452,000
Labor			52,000			146,000
Maintenance			29,000			78,000
Chemicals			23,500-35,000			185,000-278,000
Power			13,500			68,000
Fuel			6,000			59,000
TOTAL ANNUAL OPERATING COST			$124,000-$136,000			$536,000-$629,000
TOTAL EQUIVALENT ANNUAL COST			$313,500-$325,500			$988,000 $1,081,000
COST PER DRY TON OF SLUDGE			$430-$446			$135-$148

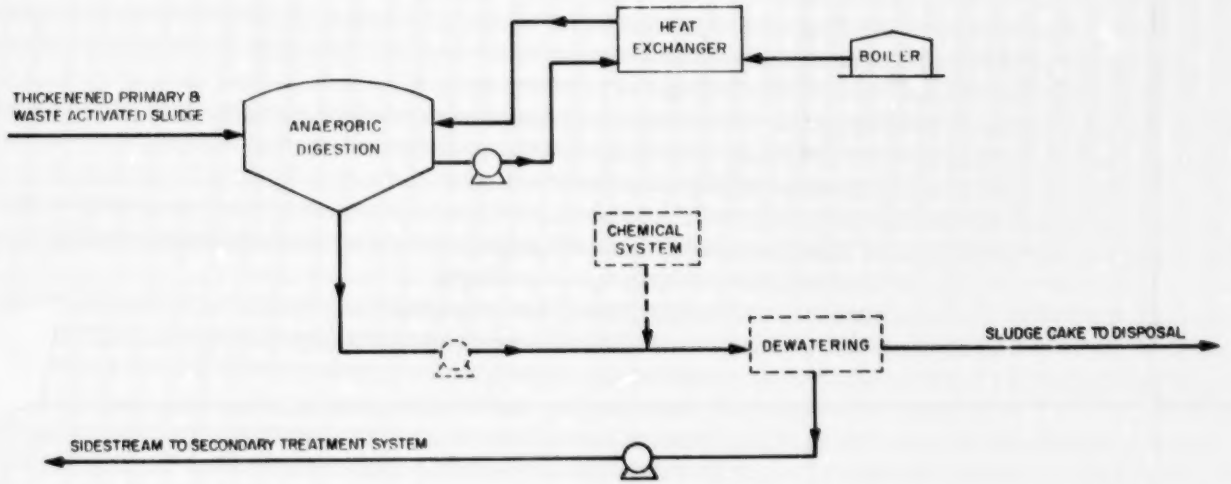

FIG. 5 FACILITIES FOR ANAEROBIC DIGESTION TREATMENT OF SLUDGE

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TABLE 9

COSTS OF ANAEROBIC DIGESTION FOR 2-MGD PLANT

Capital Costs	Cost	Amortization Factor	Annual Cost
Equipment:			
Digestion Tank Draft Tube Mixers External Heat Exchanger & Building Recirculation Sludge Pumps Boilers	$640,000	0.09439	$61,000
Total	$640,000		$61,000
Annual Operating Costs			
Labor			$12,000
Maintenance			6,000
Power			4,000
Subtotal			$22,000
Total	$640,000		$83,000

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TABLE 10

COSTS OF ANAEROBIC DIGESTION FOR 20-MGD PLANT

Capital Costs	Cost	Amortization Factor	Annual Cost
Equipment:			
Digestion Tank Draft Tube Mixers External Heat Exchanger & Building Recirculation Sludge Pumps Boilers	$2,500,000	0.09439	$236,000
Total	$2,500,000		$236,000
Annual Operating Costs			
Labor			$32,200
Maintenance			25,000
Power			12,000
Subtotal			$69,000
Total	$2,500,000		$305,000

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The amortized capital costs and operating costs total about $83,000/yr, which is about $114 per dry ton of sludge for the 2-mgd anaerobic digestion system.

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Costs for the 20-mgd Plant

Capital Costs. The total equipment cost for the 20-mgd anaerobic digestion system is about $2,500,000. The amortized capital cost is about $236,000/yr.

Operating Costs. The 20-mgd anaerobic digestion system requires an estimated 3200 man-hours per year for operations and maintenance. The estimated power requirement is 196,000 kwh/yr. Fuel for the external heat exchanger boilers is supplied by digester gas. The total operating cost is estimated to be $69,000/yr.

Amortized capital costs and operating costs total about $305,000/yr, which is about $42 per dry ton of sludge for the 20-mgd anaerobic digestion system.

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ECONOMIC COMPARISON OF ANAEROBIC DIGESTION AND HOT-ACID TREATMENT

Table 11 summarizes the costs associated with hot-acid and anaerobic digestion sludge treatment systems for 2-mgd and 20-mgd wastewater treatment plant sizes. These costs exclude dewatering component costs, as discussed earlier.

Economic comparison of the anaerobic digestion and hot-acid treatment systems indicates wide differences in capital, operating, and unit costs, especially for the smaller plant size. As expected, the hot-acid process is a very costly method of sludge treatment compared to conventional sludge treatment.

ECONOMIC EVALUATION OF LAND APPLICATION

An alternative to hot-acid treatment followed by land application is land application of digested sludge which is high in heavy metals. Section 5 of this report addressed this comparison, using the characteristics of sludge produced at Milwaukee, WI for illustration. Based on a limiting cadmium application rate, it is shown that untreated sludge requires about four times as much land as hot-acid treated sludge.

However, the impact that land requirement has on costs appears to be minimal. For land application systems, land is not purchased. Also, it is assumed that the difference in application rates is a function of the speed at which the sludge application vehicle passes over the application site, and not the number of vehicles required. Therefore, capital costs are not appreciably affected. The primary cost difference is the additional

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TABLE 11. ECONOMIC COMPARISON OF HOT-ACID AND ANAEROBIC DIGESTION TREATMENT SYSTEMS

Treatment System	2-mgd Plant				20-mgd Plant			
	Capital Cost	Annual Operating Cost	Amortized Annual Cost	Cost Per Ton	Capital Cost	Annual Operating Cost	Amortized Annual Cost	Cost Per Ton
Hot-Acid	$2,070,000	$124,000 -$136,000	$314,000 -$326,000	$430-$446	$4,900,000	$536,000 -$629,000	$ 988,000 -$1,081,000	$135 -$148
Anaerobic Digestion	$640,000	$22,000	$83,000	$114	$2,500,000	$69,000	$311,800	$42

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operation, maintenance, and fuel required for longer travel distances associated with larger land areas when land-applying untreated sludge. Based on an additional 100-miles round-trip distance required to haul untreated sludge to and from a larger land application site per day, the additional cost for a 20-tons/day operation would be about $1 per dry ton of sludge. This cost is based on a mileage estimate of 5 miles/gallon of gasoline per truck at $1.00 per gallon.

ECONOMIC COMPARISON WITH OTHER HEAVY METAL REMOVAL TREATMENT SYSTEMS

The previous discussion centered on an economic comparison of hot-acid treatment with a conventional sludge treatment system (anaerobic digestion) for the purpose of showing the additional costs associated with the removal of heavy metals from sludge. Having established this, the next step should be to compare the economics of hot-acid treatment to the economics of other systems which make special provisions for the handling of the heavy metals content of sludge. Source control of industries which contribute metals to wastewater treatment plants is used here for comparison.

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Industrial Source Control

Basis of Approach. Numerous control technologies for heavy metals have been reported in the literature. These include precipitation/clarification, ion exchange, evaporation, and reverse osmosis.

In major cities, the electroplaters are the generic group discharging the greatest amount of heavy metals to the sewer system. For this reason, this report examines technology that is compatible with the electroplating industry.

A review of EPA pretreatment criteria for the electroplating industry identified precipitation/clarification as the control strategy currently being used in the vast majority of cases, along with pretreatment for cyanide destruction and hexavalent chromium reduction. In order to balance the costs and effects of precipitation/clarification control of heavy metal discharges, an 80-percent reduction in metals from uncontrolled discharges is considered reasonable.

Industrial Source Control Cost Estimates. As part of CDM's sludge management study for New York City, analyses were made of the options available for the various sizes and types of discharges and the costs for developing heavy metal source controls. The options investigated include, for example, water conservation and precipitation/clarification for industries with flows greater than 15,000 gpd. Industries with smaller flows would use the same processes, but discharges would be hauled to regional facilities for precipitation/clarification treatment. With this regional option, which was found to be the least costly option, capital costs for source control would be about $57 million. Annual costs would be in the order of $20 million. Since there is little additional space available for pretreatment, areas currently used for production would probably be used.

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There is a lost-opportunity cost associated with those production areas. Based on a survey of industries visited, gross sales volume in New York City averages about $35/sq ft/yr. The net profit per square foot is not known, but it probably varies considerably from firm to firm. Based on $35/sq ft/yr, another $20 million per year could be attributed to industrial source control.

In addition to the electroplating industry, it is estimated that costs for treating flows from other industries would be about $25 million per year, including lost-opportunity costs.

Source control of heavy metals involves control of the non-industrial sources as well as the industrial sources. Such sources include residential/commercial, water supply, and runoff contributions. However, costing of the non-industrial controls is prohibitive because of the very diffuse nature of these control practices.

From CDM's New York City study findings presented above, even the least costly alternatives of industrial pretreatment appear to be high: approximately $40 million/yr for the electroplating industry and $25 million/yr for other metal contributing industries. The capital cost ($57 million) when amortized is about $5.4 million/yr. Therefore, the total annual cost figure for the least costly industrial source control option is about $70 million. Based on the current (1980) sludge production in New York City of about 400 dry tons per day, the unit cost of industrial source control is about $480 per ton, to effect an 80-percent reduction in heavy metal contribution from industries only. Overall, industries contribute about 48 percent of the total metal input to the City's wastewater treatment plants. Therefore, about 38 percent of the City's total heavy metal load is removed by industrial source control at a cost of $480 per ton.

In summary, when compared to the unit cost of hot-acid treatment to remove metals ($140 per ton for a 20-mgd plant, excluding dewatering), source control is shown to be much more expensive. Moreover, hot-acid treatment generally removes a greater percentage of metals, assuming successful dewatering of hot-acid sludge. This comparison indicates that hot-acid treatment is more cost-effective than source control and would be feasible in locations where metal concentrations must be decreased in order to dispose of sludge.

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